Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

THE PREDICTION STUDY OF COMPOSITE SCATTERING FROM THE SHIP ON THE SURFACE VIA SIMULATION AND EXPERIMENT

By

C.H. Fang, X.X. Cheng , F.Ding, X.N. Zhao

Science and Technology on Electromagnetic Compatibility Laboratory,
China Ship Development and Design Centre,
Wuhan China
27634073@qq.com

Abstract

Both the composite scattering of simulation and measurement of the composite targets presented. The studies were made using horizontal polarization, and for various directions of aspects, of a typical scale ship model on the surface being used as a target. The results show that the measured monostatic scattering of the composite targets with known RCS patterns are compared with their simulated values and very good agreement is obtained. In addition, some their scattering ISAR images were also described.

Keywords: Composite scattering, experimental verification, ISAR, SBR, Scale model.

C.H. Fang received the B.S. degree in applied physics from Jianghan University in 2002, and M.S degree in Materials Physics and Chemistry from Huazhong University of science and technology in China, in 2005 and PHD in EMC in China Ship Development and Design Centre in 2009. Now, he is a senior engineer in China Ship Development and Design Centre. His research interests in EMC, EMI and scattering.

This use of this work is restricted solely for academic purposes. The author of this work owns the copyright and no reproduction in any form is permitted without written permission by the author.

1. Introduction

- The problem of scattering from composite targets is of great importance in both radar cross section reduction (RCSR) and electromagnetic compatibility (EMC) studies. It is well-known that the radar cross section of a ship on the sea can be significantly affected by the sea state. And the interaction of the incident electromagnetic field and the scattered wave with the rough sea surface causes variations in the RCS as a function of azimuth angle. Traditionally, the problem of calculating the RCS of a ship on the ocean is treated by the varied analysis methods.

- The radar scattering from rough surfaces, such as sea-like surfaces, has been widely treated in the literature. A review can be found in a special issue about the topic in [1]. An accelerated version of the Generalized Forward- Backward (GFB) method, introduced in [2], is used to generate the numerical data for the Monte Carlo simulation. Most related advances have been focused on the direct numerical simulation of the scattering problem. Numerical techniques are mostly based on integral equation formulations, such as the Method of Moments (MOM) [3]. And then, several authors have been investigated the scattering from obstacles on rough surfaces. Pino et al. [2] developed the Generalized Forward-Backward method for computing the scattering from obstacles on a sea surface, based on the Forward- Backward method proposed by Holliday et al. [4].

- In [5], West and Sturm tested several different iterative solutions to the MOM equations for the scattering from large breaking waves. What's more, the NRCS and ISAR images of rough sea surface are computed according to the facet model proposed in [6-12]. In addition, C. H. Fang simulated the backscattering from sea surface and a ship on the sea by fractal model and Multilevel Fast Multipole Method (MLFMM), respectively [13-14]. However, little work has been done to address the experimental verification and imaging analysis of scattering from composite targets, especially for the ship on the sea.

- In this paper, a study for simulation and experimental verification of scattering from composite targets is presented. The compared results show that the curve of RCS of experiment is agreed well with the result of Shooting and Bouncing Rays (SBR) method. What's more, since the two-dimensional (2-D) inverse synthetic aperture radar (ISAR) image can represents the magnitude and locations in both down-range and cross-range of each scattering center on a complex radar target, some related 2-D ISAR images have also shown.

2.Simulation and measurement methods

- **2.1 Simulation method**
- The SBR technique is outlined in the previous section and explained in detail in earlier publications [15-18]. The scattered far field from a scatterer is the sum of contributions from many ray tubes that strike the scatterer. Usually, we enclose the scatterer by an arbitrary surface C, called the exit aperture. The scattered field for a given ray tube over C is approximately determined by SBR, and is denoted by (Eap, Hap). At an observation point (r, θ, φ) in the far field, the contribution from this ray tube is expressed by

$$E(r,\theta,\varphi) \approx \frac{e^{-jkr}}{r}(\hat{\theta}A_{\theta} + \hat{\varphi}A_{\varphi}), kr \to \infty \qquad (1)$$

- By Huygens' principle, it is related to the aperture fields (Eap, Hap) by the surface integral [19]

$$\begin{bmatrix} A_\theta \\ A_\varphi \end{bmatrix} = \left(\frac{jk}{2\pi}\right) \iint_{tube} e^{-jkr'} \left\{ \begin{bmatrix} -\hat{\varphi} \\ \hat{\theta} \end{bmatrix} * E_{ap}(r') f_e + Z_0 \begin{bmatrix} \theta \\ \hat{\varphi} \end{bmatrix} * H_{ap}(r') f_h \right\} * \hat{n} dx' dy' \quad (2)$$

- The corresponding configuration of scattering simulation is presented in Figure 1. In particular, the scale model of a ship was selected on the sea as the typical object of study

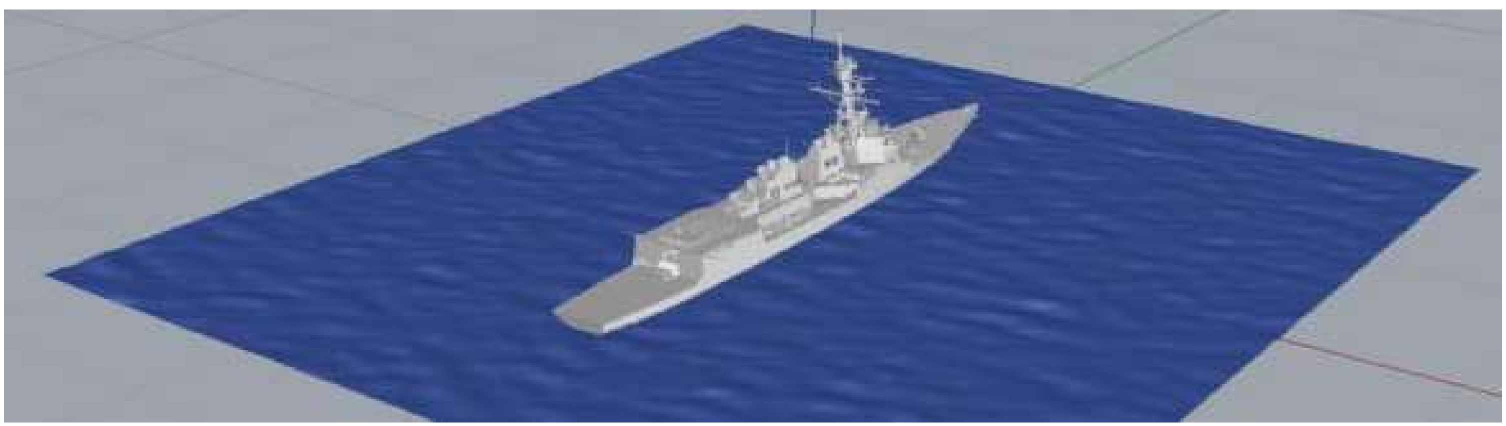

Figure 1: The configuration of scattering simulation.

- Here we shall incorporate a sea spectrum that agrees well with the experimental data into the fractal model to represent a fully developed sea surface. Therefore, the two-dimension rough sea surface is modeled by [6]

$$f(x,y)=\sigma C\sum_{i=1}^{i\max}\sum_{j=1}^{j\max}S\left(k_x,k_y\right)\sum_{n=0}^{N-1}(D-2)^n\times$$
$$\sin\left[k_0b^n\left(x\cos\theta_n+y\sin\theta_n\right)+j_n\right]$$

- where is the semi-empirical sea spectrum developed by A.K.Fung and is of the form:

$$S(k,\phi)=S(k)[a_0+a_1(1-e^{-bk^2})\cos 2\phi]$$

$$S(k)=\begin{Bmatrix}S_1(k), & k<0.04\\ S_2(k), & k>0.04\end{Bmatrix}$$

$$S_1(k)=\frac{a_0}{k^3}\exp\left(\frac{-0.74g^2}{k^2u^4}\right)$$

$$S_2(k)=0.875(2\pi)^{p\text{-}1}(1+\frac{3k^2}{k_m^2})\times\ g^{(1\text{-}p)/2}[k(1+\frac{k^2}{k_m^2})]^{\text{-}(1\text{-}p)/2}$$

- where , is the friction velocity in centimeters per second and is related to the wind speed at altitude in centimeters above the mean sea level by

$$u = (u_* / 0.4) \times \ln\left(\frac{z}{0.684 / u_* + 4.28 \times 10^{-5} u_*^2 - 0.0443}\right) cm/s$$

$$a_0 = \frac{1}{2\pi}, a_1 = \frac{(1-R)/(1-R)}{\pi(1-B)}$$

$$B = \frac{1}{\sigma_t^2} \int_0^\infty k^2 S(k) e^{-bk^2} dk$$

$$\sigma_t^2 = \sigma_{ut}^2 + \sigma_{ct}^2 = \int_0^\infty k^2 S(k) dk$$

$$R = \frac{\sigma_{ct}^2}{\sigma_{ut}^2} = \frac{0.003 + 1.92 \times 10^{-3} u}{3.16 \times 10^{-3} u}$$

- Meanwhile, the set up of parameters of simulation and measurement is shown in the following table

Parameters	*Values*
Azimuth angles Elevation angle	0°-360° 30°
Polarization	HH

- **2.2 measurement method**
- The configuration of scattering measurement facility is shown in Figure 2. And the scale factor of the ship model is 1:150. The measurements took place in a pool in China.

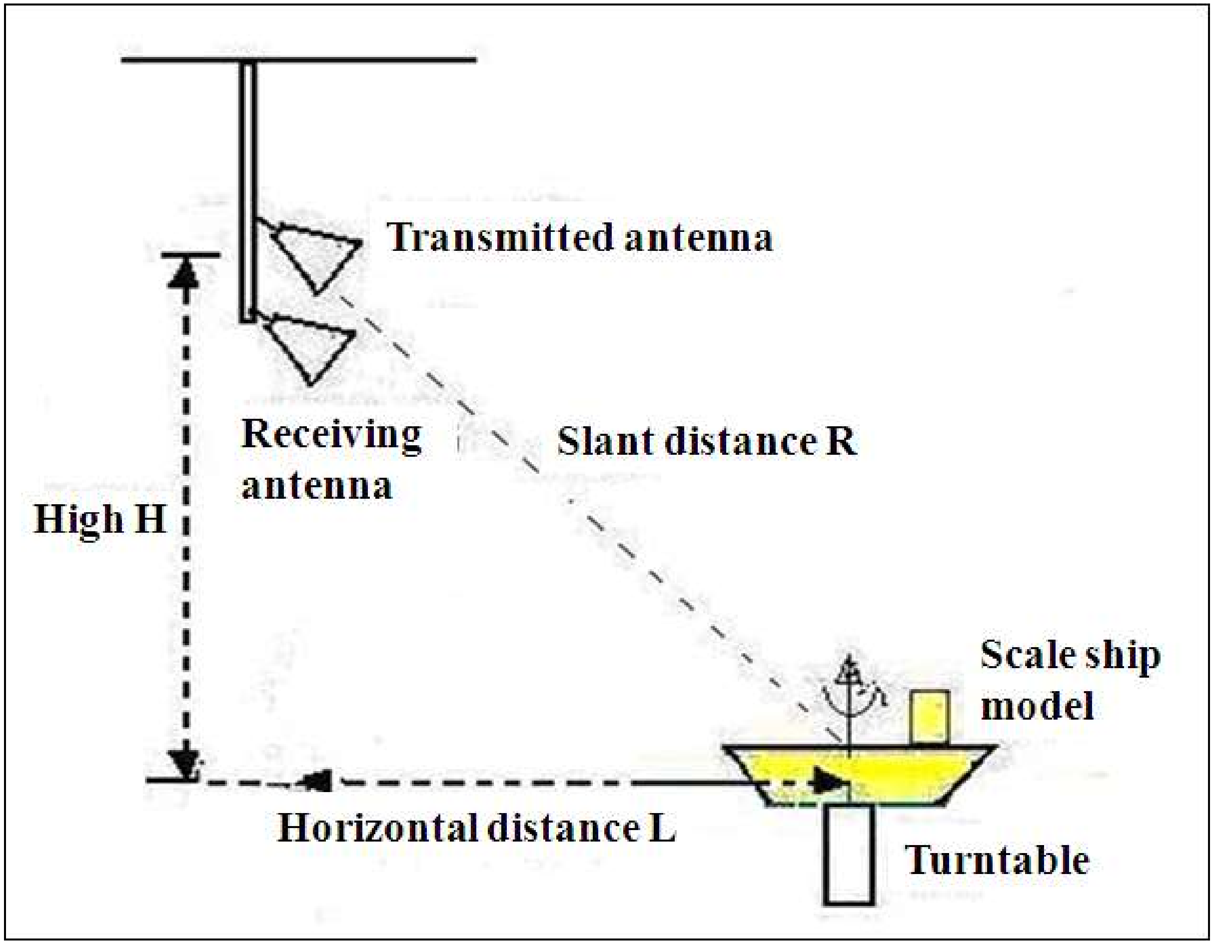

Figure 2: The configuration of scattering measurement facility.

3. Results and Comparion

- Figure 3 shows the results of simulation (blue line) and measurement (red line) of full scale model on the surface. It is well known that according to the scale principle in electromagnetics, the data of full scale model should be revised with log150, namely 21.8dB, from the direct experimental data.
- In this figure, we can see that the comparison of the SBR results with the tested solutions showed fairly good agreement over the 360 degree range of incident angles from nose-on except for particular directions such as 0º, 180º and 270º. This discrepancy is due to the fact that exact azimuth information is not easy to determinate by instruments and so the error of aiming appears in these directions.

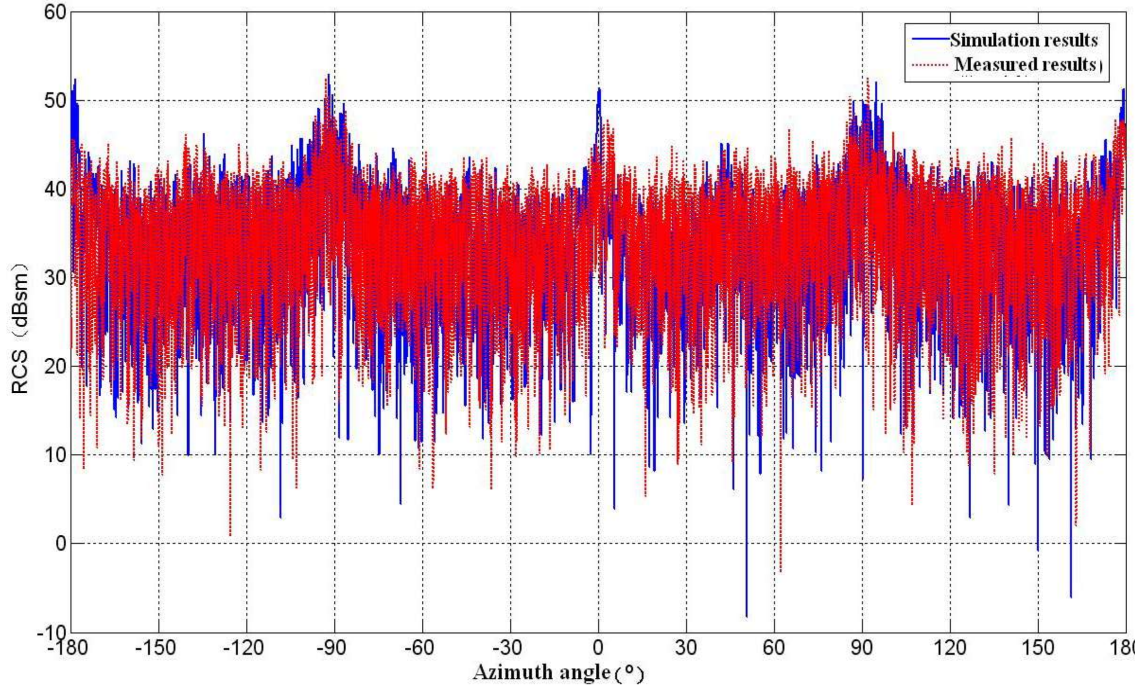

Figure 3: The comparison of simulation and measurement of full scale model on the surface.

Figure 4-10 show the ISAR images of the scale model of ship on the surface measured in a pool under different azimuth angles. And we can see the clear frame of the main constructions, such as superconstruction and fore etc. In addition, it is worth noting that under azimuth angle 180°, the coupling between the ship and the surface can be seen distinctly. What's more, the similar phenomenon is also discovered under azimuth angle 90°.

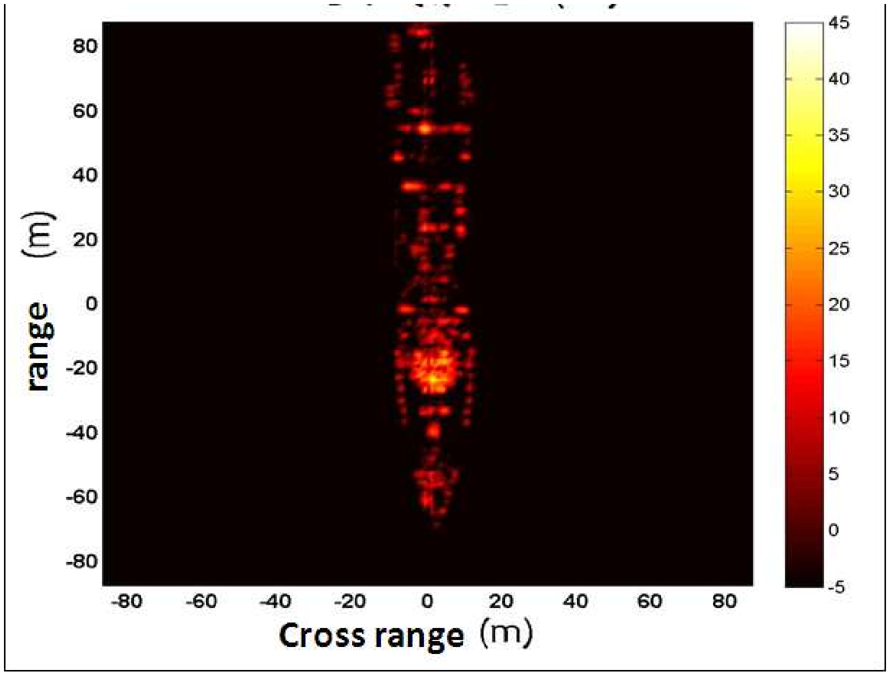

Figure 4: ISAR image of the ship on the sea for azimuth angle 0^o.

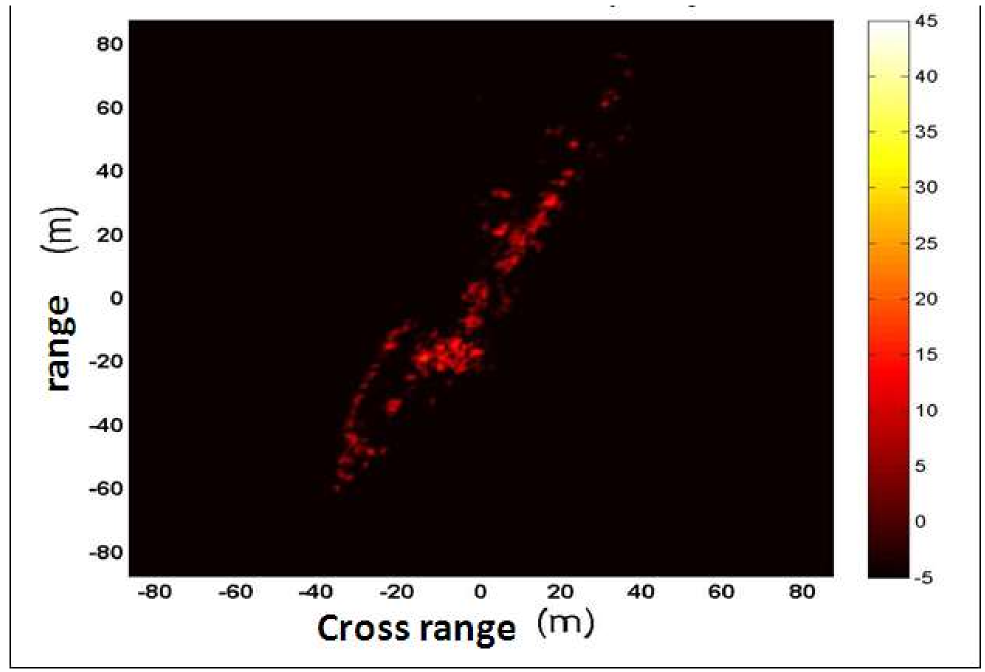

Figure 5: ISAR image of the ship on the sea for azimuth angle 30^o.

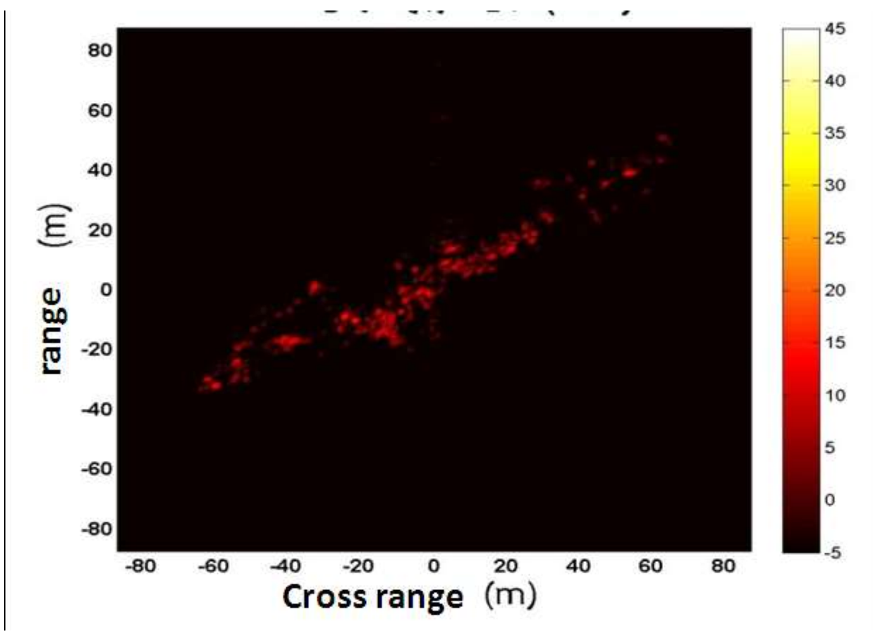

Figure 6: ISAR image of the ship on the sea for azimuth angle 60^o.

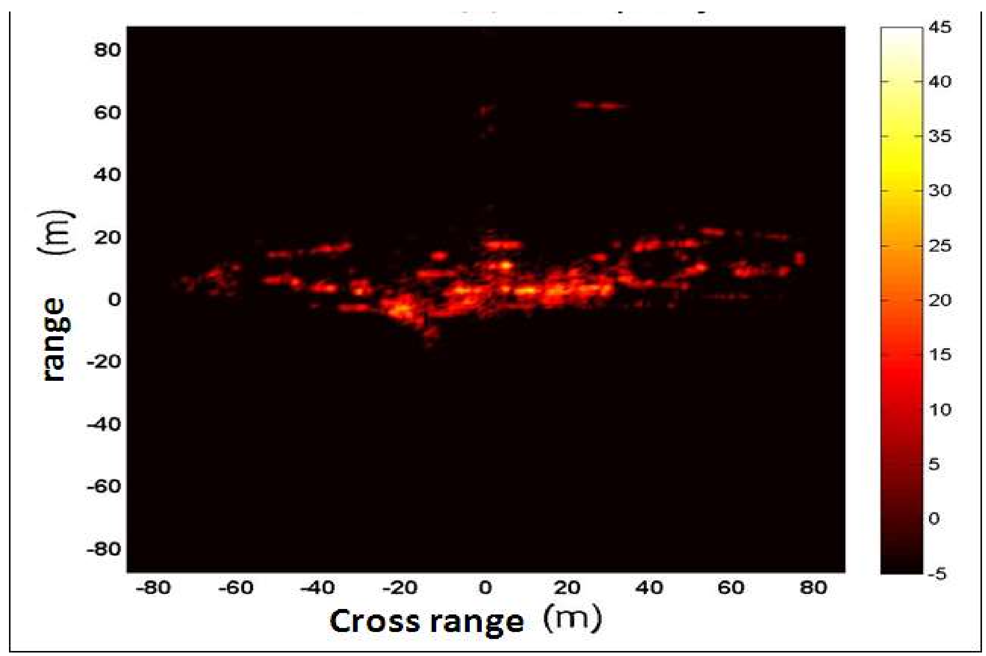

Figure 7: ISAR image of the ship on the sea for azimuth angle 90^o.

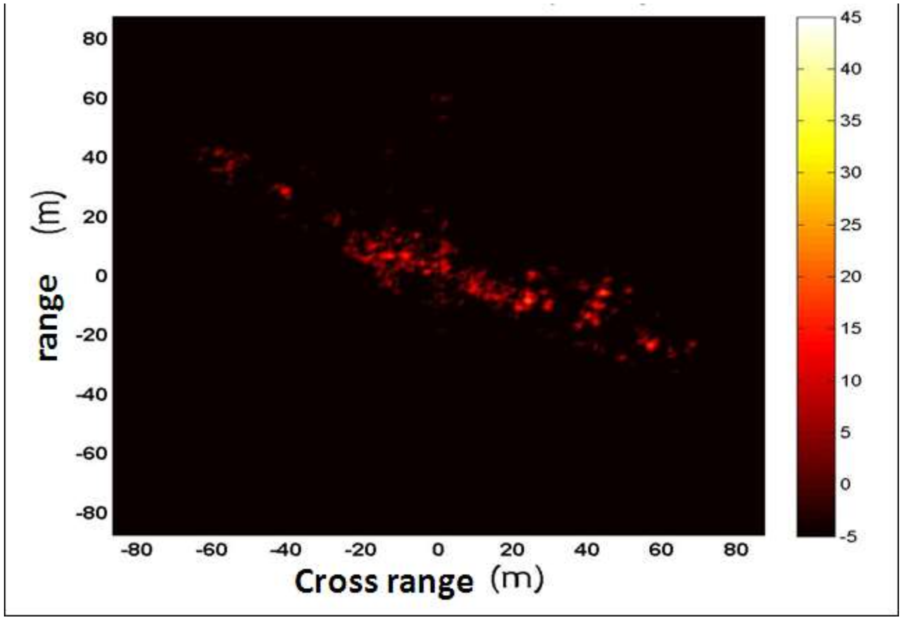

Figure 8: ISAR image of the ship on the sea for azimuth angle 120°.

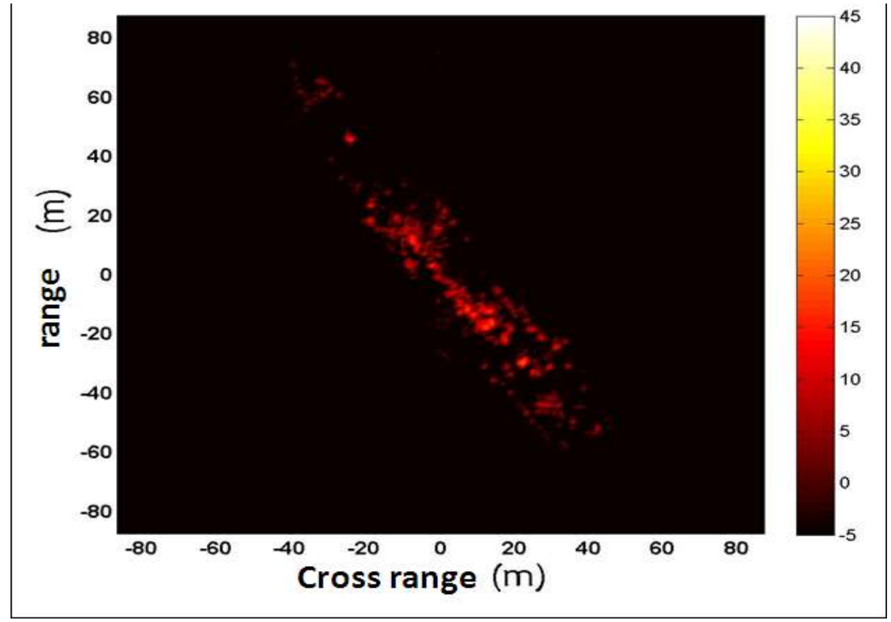

Figure 9: ISAR image of the ship on the sea for azimuth angle 150°.

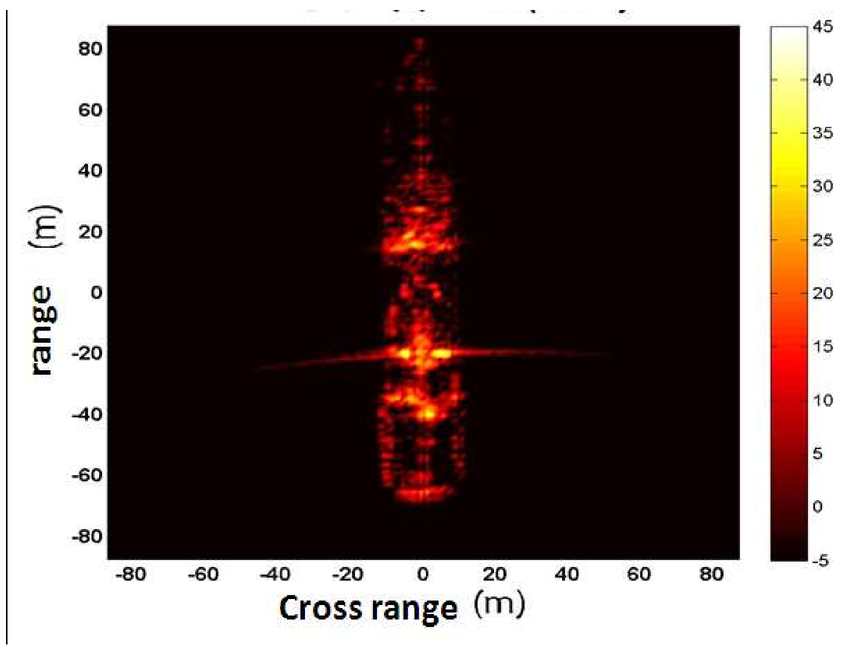

Figure 10: ISAR image of the ship on the sea for azimuth angle 180°.

4. Conclusions

- In summary, the simulation and experiment of composite scattering of about a ship model on the surface were presented in this paper. And the compared results show that in the appropriate conditions, the RCS patterns of measured and calculated results have shown good agreement. Moreover, the ISAR images of the scale model of ship on the surface measured in a pool under different azimuth angles which illuminate the effects of the composite scattering. More detailed study on the case of the ship with absorbing material is left for a future work.

References

[1] G. S. Brown. “Special Issue on Low-Grazing-Angle Backscattering from Rough Surfaces”, *IEEE Transactions on Antennas and Propagation*, AP-46, pp. 2028-2031, 1998.

[2] M. R. Pino, L. Landesa, J. L. Rodriguez, F. Obelleiro, and R. J. Burkholder. “The Generalized Forward-Backward Method for Analyzing the Scattering from Targets on Ocean-Like Rough Surfaces”, *IEEE Transactions on Antennas and Propagation*, AP-47. 6. 1999.

[3] R. F. Harington, Field Computation by Moment Methods, New York, IEEE Press, 1993

[4] D. Holliday, L. L. DeRaad, and G. J. St-Cyr. “Forward-Backward: A New Method for Computing Low-Grazing Angle Scattering”, *IEEE Transactions on Antennas arid Propagation*, AP-44, pp. 722-729, 1996.

[5] J. C. West and J. M. Sturm. “On Iterative Approaches for Electromagnetic Rough-Surface Scattering Problems”, *IEEE Transactions on Antennas and Propagation*, AP-47, 8, pp. 1281-1288, 1999.

[6] H. Chen, M. Zhang, Y. W. Zhao, and W. Luo, An Efficient Slope deterministic Facet Model for SAR Imagery Simulation of Marine Scene, *IEEE Transactions on Antennas and Propagation*, 58(11), pp.3751-3756, 2010.

[7] M. Zhang, H. Chen, and H. C. Yin, Facet-Based Investigation on EM Scattering From Electrically Large Sea Surface With Two-Scale Profiles: Theoretical Model, *IEEE Transactions on Geoscience and Remote Sensing*, 49(7), pp.1967-1975, 2011.

[8] H. Chen, M. Zhang, and H. C. Yin, Facet-based Treatment on Microwave Bistatic Scattering of Three-Dimensional Sea Surface with Electrically Large Ship, *Progress In Electromagnetics Research*, 123, pp.385-405, 2012.

[9] H. Chen, M. Zhang, and H. C. Yin, Facet-based simulator for bistatic scattering of maritime scene with electrically large ships: Slope Summation Facet Model, *International Journal of Remote Sensing*, 33(21), pp.6927-6941, 2012.

[10] M. Zhang, H. Chen, P. Zhou, and X. Y. Zhang, An Efficient Simulated Sea Slope Model for Backscattering from a Non-Gaussian Sea Surface, *Chinese Physics Letters*, 26(9), pp. 094102, 2009.

[11] S. D. An, X. Fang, W. D. E, Z. Qi, The electromagnetic analysis in ship RCS plastics design, *Chinese Journal of Ship Research*, Vol. 4, No. 3, pp.52-55, 2009.

[12] W. Nan, C. Jiong, Discussion on the RCS simulation test of naval ships on water surface, *Chinese Journal of Ship Research*, , Vol. 7, No. 5, pp.103-106, 2012.

[13] C. H. Fang, Q. Liu and X. N. Zhao. “Integrated Model of Electromagnetic Scattering for Two Dimensional Fractal Sea Surface”, *International Journal of Modern Physics B*, Vol. 24, No. 22, pp. 4217-4224, 2010.

[14] C. H. Fang, Q. Zhang and S. X. Yang. “Influence of vibration between shipboards on ship-sea integrational electromagnetic Scattering in high frequency”, 2010 *International Symposium on Signals, Systems and Electronics, ISSSE2010 –Proceedings*， pp. 697-700, 2010.

[15] H. Ling, R. Chou, and S. W. Lee. “Shooting and bouncing rays: Calculating the RCS of an arbitrarily shaped cavity,” *IEEE Trans. Antennas Propagat.,* vol. 37, pp. 194-205, Feb. 1989.

[16] H. Ling, S. W. Lee, and R. C. Chou, “High-frequency RCS of open cavities with rectangular and circular cross sections, ” *IEEE Trans. Antennas Propagat.,* vol. 37, pp. 648-654, 1989.

[17] R. C. Chou and S. W. Lee, “Radar cross-section reduction studies of partially open cavity structures,” *Int. J. Numerical Modeling: Electronic Networks, Devices, and Fields,* vol. 1, pp. 207-220, 1989.

[18] P. H. Pathak and R. J. Burholder, “Modal, ray, and beam techniques for analyzing the EM scattering by open-ended waveguide cavities,” *IEEE Trans. Antennas Propagat.,* vol. 37, pp. 635-648, May 1989.

[19] J. Baldauf and S. W. Lee, “High Frequency Scattering from Trihedral Corner Reflectors and Other Benchmark Targets: SBR Versus Experiment,” *IEEE Trans. Antennas Propagat.,* vol. 39, no. 9, pp. 1345-1351, Sept 1991.